Multi-band astronomy with LISA

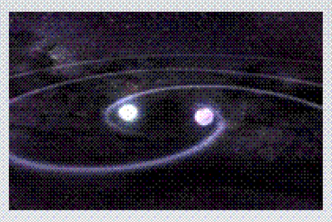
G. Branduardi-Raymont[1], G. Ramsay[1], C. Wang[2], R. Bingham[3], J. T. Mendonca[4]

[1] Mullard Space Science Laboratory, Department of Space and Climate Physics, University College London
[2] University of Aberdeen, Aberdeen, Scotland
[3] Rutherford Appleton Laboratory, Oxon, England
[4] Instituto Superior Tecnico, Lisbon, Portugal

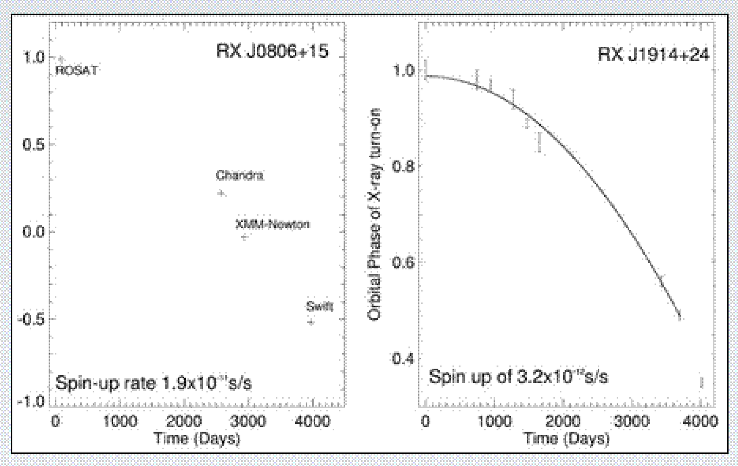
LISA will return unprecedented data on GW sources; however, its full science potential will be realised only by matching the sources with astrophysical counterparts and correlating their properties over the EM spectrum. Different types of sources require different approaches: direct identification with known EM sources in some cases (like for ultra-compact binaries), and statistical estimation from the systems EM characteristics in others (such as for MBH merger and EMRI rates). In turn, knowledge of the EM properties (e.g. for the ultra-compact binaries) will be crucial in constructing accurate waveforms to aid LISA's signal processing. The consequences of the interaction between GW and EM radiation may also have important implications, for instance on events such as gamma-ray bursts. It is clear that a large degree of synergy is needed between the GW and EM astrophysical communities, in order to build a strong programme of coordinated studies targeted to the needs of LISA. We describe on-going astrophysical work relevant to these considerations.

Ultra-compact binaries

Ultra-compact binaries with white dwarf secondaries are predicted to be both numerous and strong GW sources. Indeed, these binaries will be the so-called 'verification binaries' for LISA. Recent work has shown that the strongest gravitational source, RX J0806+15, should be detectable using LISA in less than 1 week (Stroeer & Vecchio 2006).

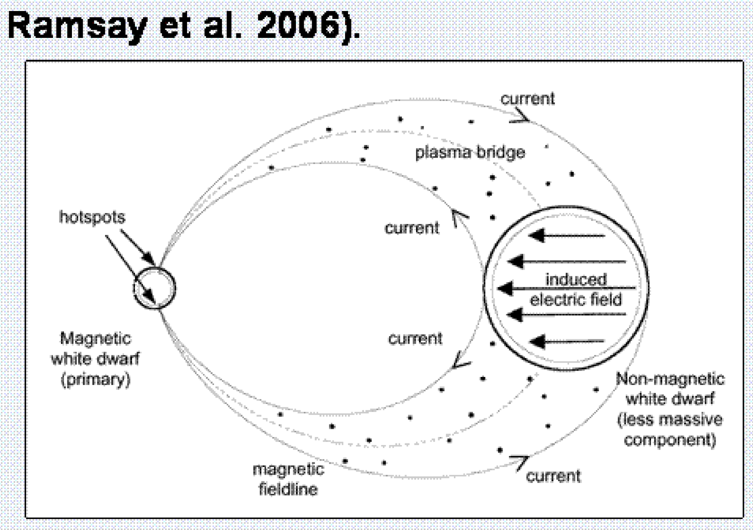


The effects of gravitational radiation can be observed directly in RX J0806+15 (binary orbit of 321 sec) and RXJ1914+24 (569 sec). Observations show that both these systems are spinning up, i.e. their orbit is shrinking.



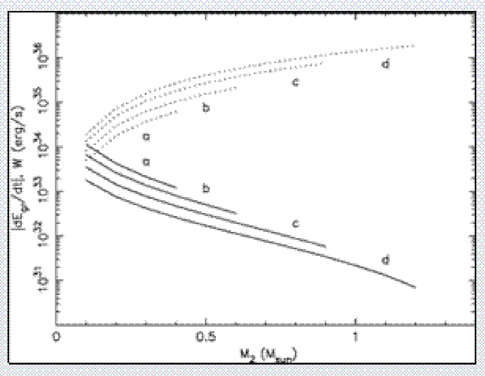
However, the exact mechanism which powers the EM emission in these systems has not been settled. The proposed models fall into two general categories – accretion-powered and non-accretion-powered. The non-accretion model is that of the so-called 'Unipolar-Inductor' (UI, Wu et al. 2002). Although it has still to be proved definitively, this model is so far the one which best describes the EM observations of these systems (e.g. Ramsay et al. 2006).

In the UI model, large electrical currents are driven as a conducting body (the secondary white dwarf) orbits a magnetic body (the primary white dwarf): these currents are dissipated at foot-points on the primary. The currents are so powerful that emission occurs in the X-ray band - the X-rays irradiate the secondary white dwarf and give rise to the anti-phase between X-ray and optical lightcurves (Ramsay et al. 2000).



Determining the mechanism which powers the EM emission is crucial in interpreting the observed spin-up rates seen in both RXJ0806+15 and RX J1914+24 (Hakala et al. 2004, Ramsay et al. 2006). If UI is powering the EM emission, then their orbital evolution is determined jointly by gravitational radiation losses and EM interactions (Dall'Osso et al. 2006, Willes, Wu & Ramsay 2006).

Power of electrical dissipation (solid lines) and GW (dotted) from UI systems with 9.5 min orbital period (cf. RXJ1914+24). Curves a, b, c and d correspond to systems with a 0.5, 0.7, 1.0 and 1.3 solar mass primary magnetic white dwarf (Wu et al. 2002).



Only by knowing the relative proportion that each mechanism contributes to the spin-up can we correctly predict their GW signal.

There are reasons to expect that unipolar induction could operate in other binary systems, including a white dwarf orbiting a rotating black hole. This would affect the system's orbital evolution and hence the expected gravitational signal.

How many?

White dwarf - white dwarf binaries are expected to make a significant contribution to the background gravitational signal in the LISA pas-band. Correctly modelling this background signal is essential for accurately predicting the sensitivity of LISA observations.

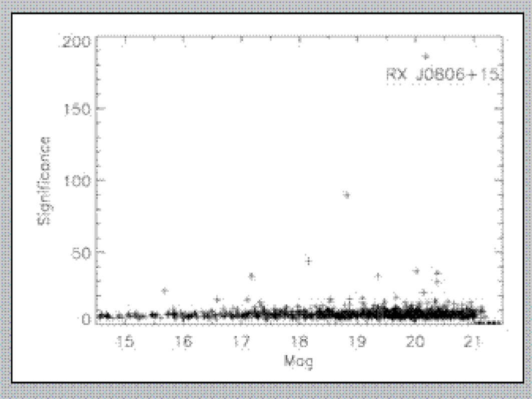
Theoretical models of stellar populations and binary evolution suggest that interacting white dwarf - white dwarf binaries are common place in our Galaxy. However, less than 20 of such interacting binaries are known. Currently it is not clear whether this discrepancy is due to inadequacies in the theoretical models or that many more interacting binaries await discovery.

A number of projects are on-going to test this question by searching for new systems. The SPY project (Sn Ia Progenitor surveY), for instance, searches for radial velocity variations in a large sample of faint white dwarfs (Napiwotzki et al. 2001). The aim is to determine the orbital period distribution of such binaries and also test whether these systems can give rise to type Ia supernovae.

A different approach is provided by RATS (RApid Temporal Survey, Ramsay & Hakala 2005). This study searches for stellar sources whose intensity varies on short periods: from a few min to periods longer than several hours.

A pilot field included the binary RX J0806+15 (orbital period 321 sec): such kind of system can easily be detected.

The RAT Survey is on going but initial results suggest that theoretical models significantly overestimate the space density of interacting white dwarf - white dwarf binaries.



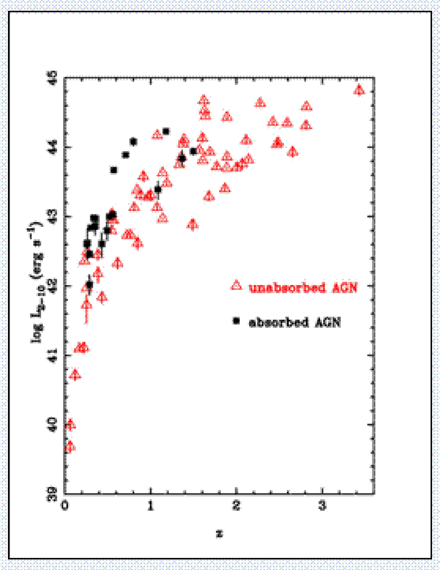
Super Massive Black Holes (SMBH) as GW sources

Predictions of event rates of both, SMBH binary mergers and EMRIs, are heavily dependent on the universal mass density distribution of SMBHs. A strong correlation has been established between SMBH mass and galactic velocity dispersion (and a weaker one with luminosity of the host galaxy's stellar bulge). The correlation has been used to derive the local SMBH mass density.

The AGN luminosity function as a function of redshift, i.e. the representation of their evolution with cosmic time, traces the accretion history of the BH and gives a measure of the accreted mass density, and ultimately the mass distribution of SMBHs (Yu & Tremaine 2002). Such calculations have been based so far on the luminosity function of optically bright QSOs.

However, a discrepancy exists between the strong optical evolution of AGN at $z <\sim 2$, and the X-ray luminosity function which peaks at $z \sim 1$. The existence of a significant number of absorbed AGN making up a large fraction of the entire population may explain this inconsistency. Deep pencil-beam X-ray surveys of AGN appear to indicate that the amount of obscuration is strongly luminosity-dependent, with the fraction (>75%) of obscured AGN being larger at low luminosities.

On the other hand, *XMM-Newton* large area surveys (Dwelly & Page 2006) show that the pattern of absorption in AGN is independent of both redshift and luminosity, with obscured AGN being ~ 3 times more populous than un-obscured ones at all redshifts and luminosities. This is illustrated by the presence of absorbed objects (black symbols) in a L_x – z plot (from Page et al. 2006).



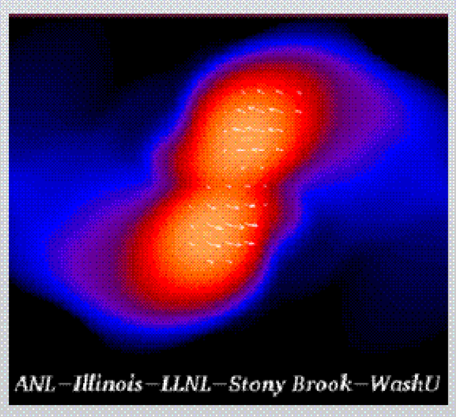
Moreover, the space density of X-ray selected AGN has been found to be up to a factor of 40 larger than that of bright optically selected QSOs (Hasinger et al. 2005).

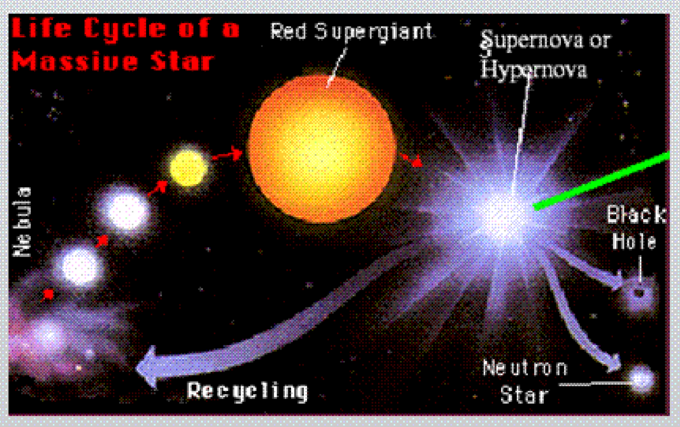
These results require that estimates of the SMBH mass distribution be reconsidered.

Our knowledge of the demographics and evolution of AGN, and thus the accuracy of the SMBH mass distribution, is bound to improve further as we plan to combine the wide angle, deep ***XMM-Newton*** surveys with mid-infrared (*Spitzer*) imaging surveys: these have the potential of revealing the most distant and heavily absorbed AGN.

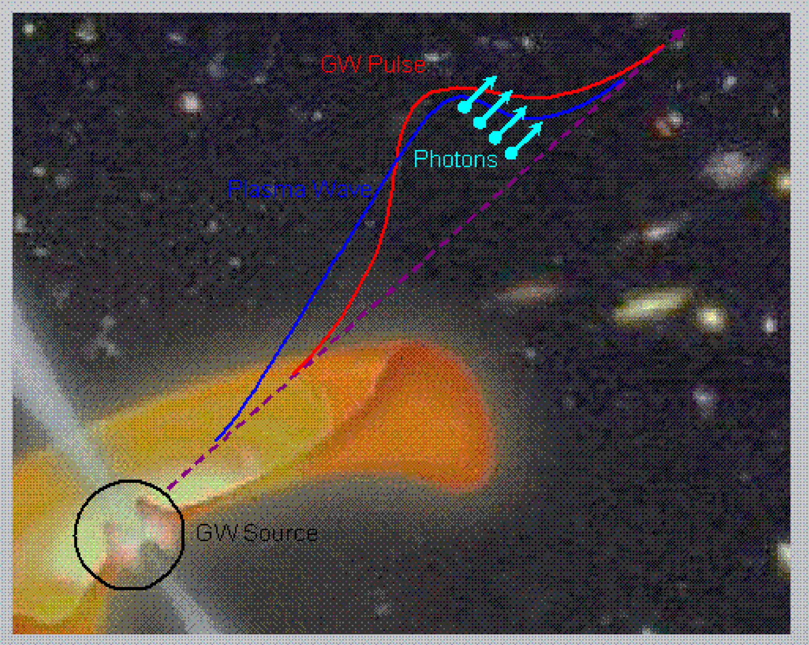
Gamma-Ray Bursts (GRBs)

The detection by *Swift* of more than 120 GRBs so far has already revolutionarised our view of these most energetic phenomena, which are thought to be associated with the coalescence of neutron stars and black holes, and thus GW production. As statistics improve with more bursts being detected, the characterisation of larger samples of short (< 2 sec) and long bursts will provide an estimate of the relative frequency of the different types of mergers, be coalescent neutron stars, black hole mergers or hypernova events.





Photon energy up-shift by plasma waves induced by GW from a compact source (c.wang@abdn.ac.uk)



The highly non-linear nature of GW at source results in the coupling to other wave modes such as plasma waves. The generation of these wave modes causes an attenuation of the GWs. For strong GW burst models the Bondi-Sachs metric has been used to evaluate the non-linear modification of the effective refractive index. These models show that photons and high-energy particles can experience a significant energy shifts by 'surfing' on the plasma waves. This effect may have important implications on gamma ray events such as GRBs and causal gravitational and EM wave observations.